



Large Low Temperature Silicon Carbide Mirrors

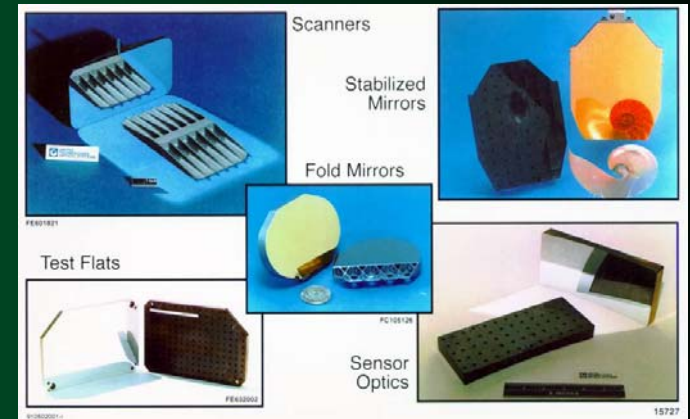
Mark A. Ealey

Silicon Carbide Optics and Structures

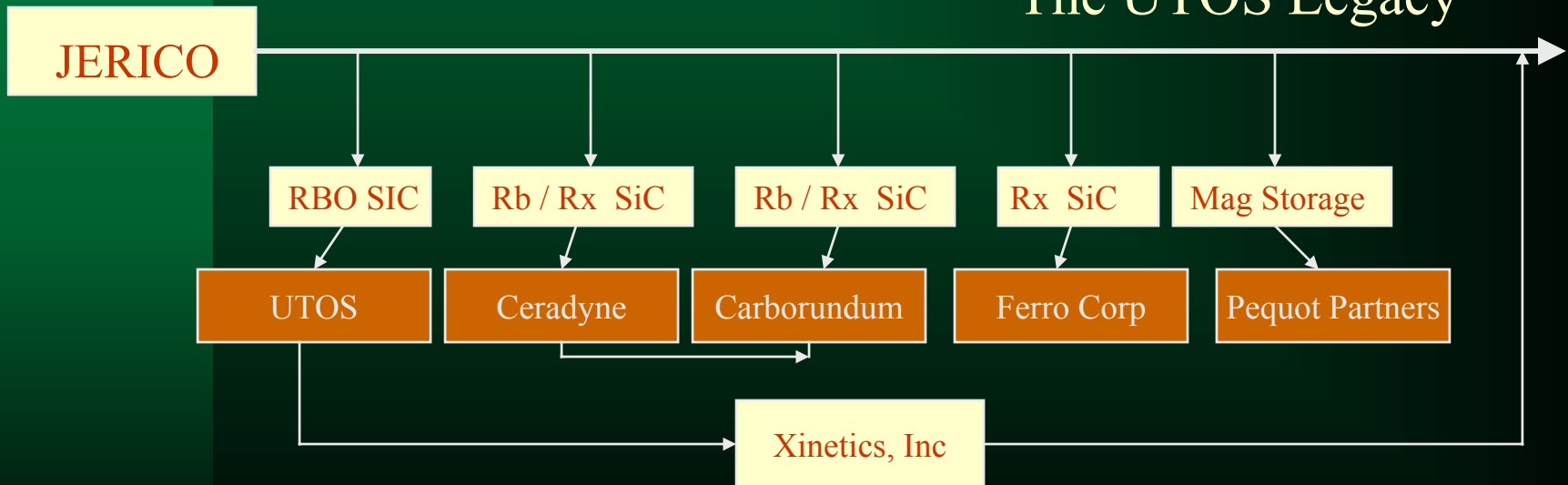
... Xinetics Purchases UTOS Technology in 1995

– Legacy

- Jeri* formed in 1981 – SiC Materials & Structures Specialty
- UTOS began in 1982 – Optics Specialty



The UTOS Legacy



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Silicon Carbide Optics and Structures

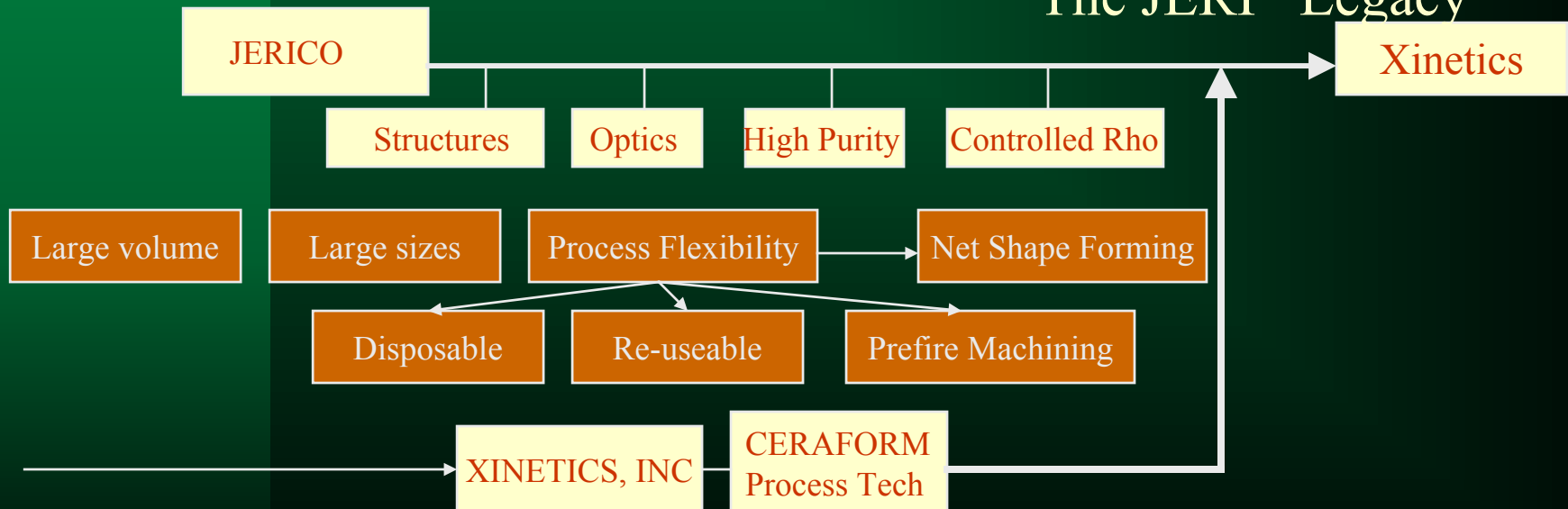
... Xinetics Purchases JERI* in 2000

– Legacy

- Jerico SiC technology combined with Xinetics' / UTOS SiC technology



The JERI* Legacy



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Silicon Carbide Optical Structures

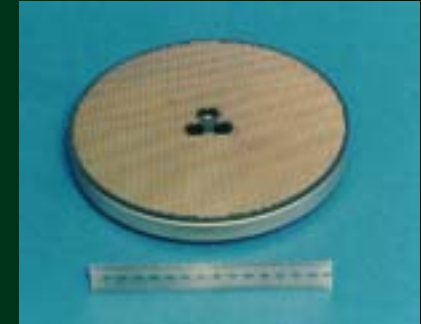
... Near Net Shape with Integral Interface Features



**Small & Large SiC
Polishing Laps**



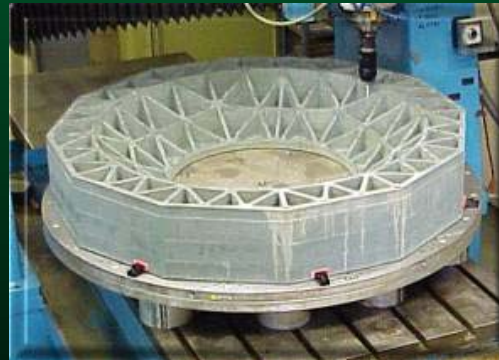
**15-cm All Silicon Carbide
Telescope Structure**



**300-mm Silicon Carbide
Vacuum Chuck**



**37-Inch IFX RCIS
First Article**



**52-Inch ALPHA BCIS
First Article**



**36-Inch ALPHA BCIS
First Article**

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Program Goals



Program Goals

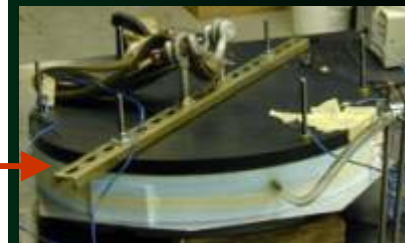
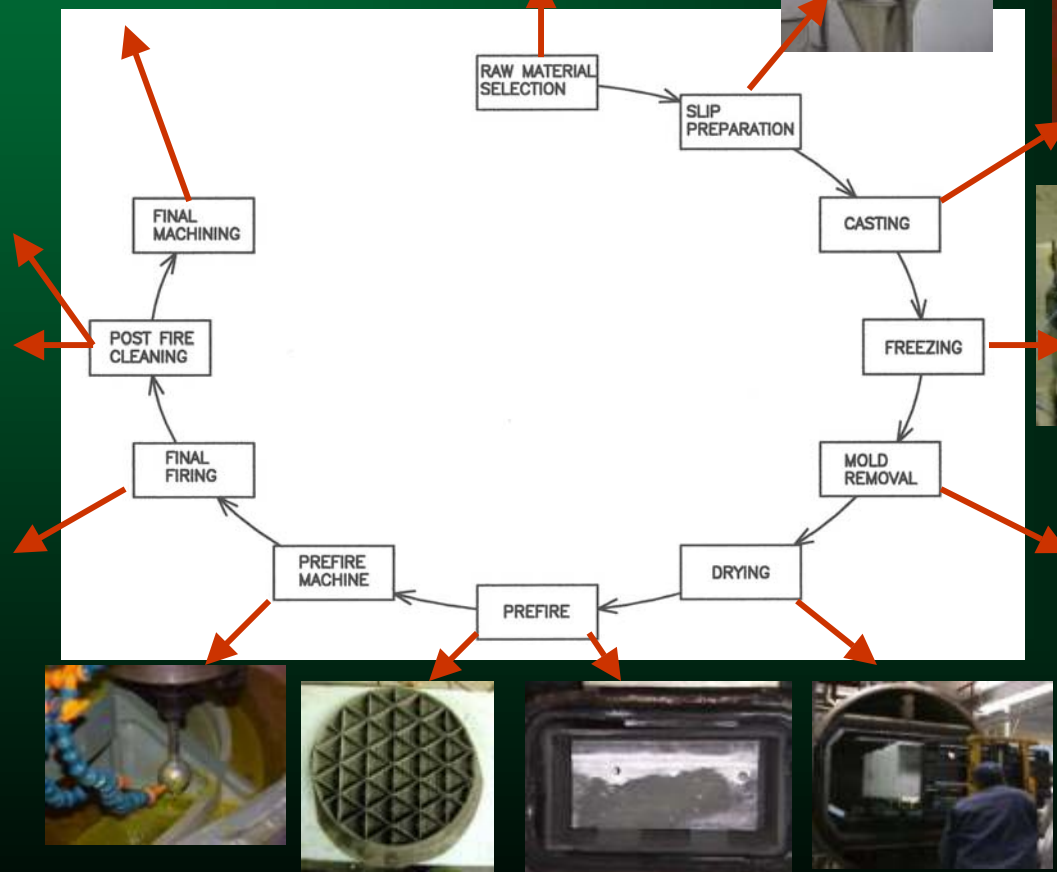
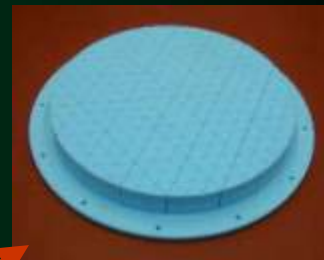
- ◆ Develop Polishing Process for Both Bare and Silicon Clad Reaction Bonded SiC
- ◆ Evaluate Polishing Vendors
- ◆ Scale Ceraform Process to 0.5m polishable optics with areal density $\sim 10\text{kg/m}^2$
- ◆ Develop Ceracore Ultralightweight SiC Processing to Produce $<10\text{kg/m}^2$ polishable optics
- ◆ Plan for Scaling of Optics to 1 meter class and beyond



CERAFORM Process

Xinetics Critical Facilities and Equipment

... 1.7-m SiC Fabrication Demonstrated

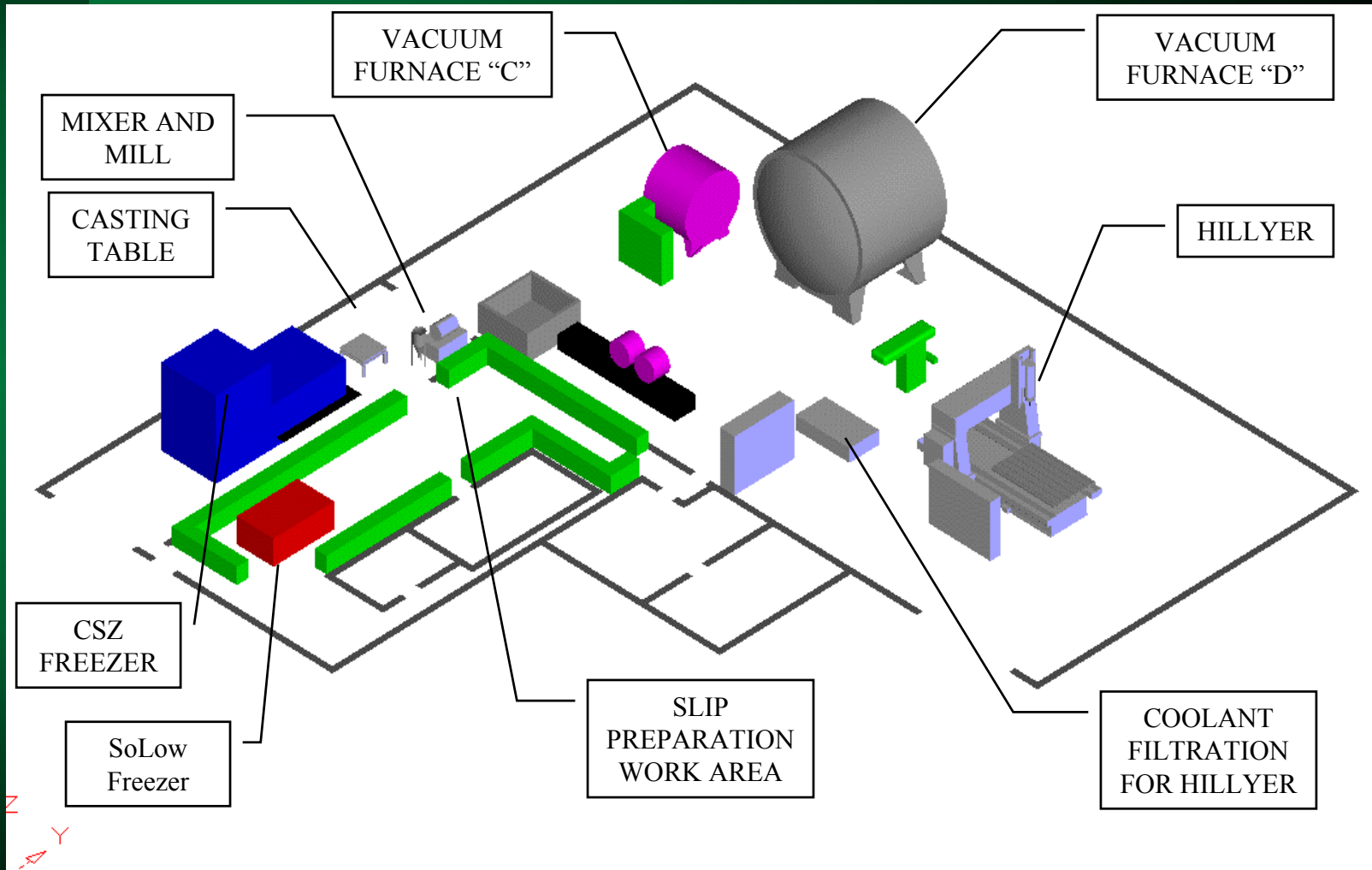


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Xinetics 2-Meter Facility Layout



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Xinetics Critical Facilities and Equipment for 2-Meter SiC Fabrication



SiC Power Inventory



Slip Preparation



Slip Preparation



Large Vacuum Furnace



CNC Machining and Inspection



Cleaning and Finishing

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Design Trades



Material Property Comparison

SiC offers advantages structurally and thermally

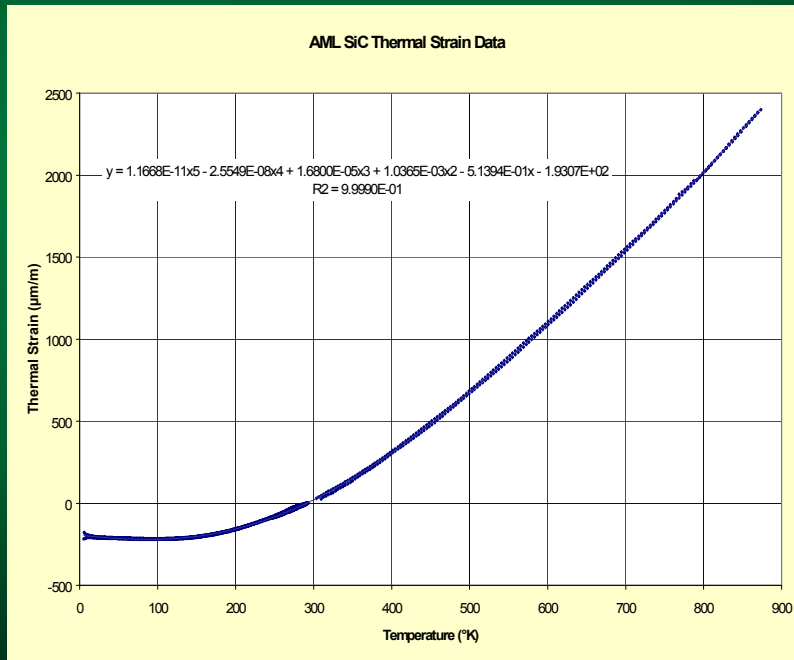
		Be	Ceraform SiC	ULE	Al
Elastic Modulus	Msi	44	45	9.8	9.9
Density	g/cm ³	1.85	2.95	2.21	2.71
Coefficient of Thermal Expansion	ppm/°C	11.4	2.44	0.03	22.7
CTE Uniformity	ppb/°C	100	30	10	100
Thermal Conductivity	W/m °C	180	156	1.31	155
Specific Heat	J/Kg °C	1925	670	766	879
Thermal Diffusivity	m ² /s	0.607	0.870	0.008	0.653
Mircoyield	Ksi	5.0	NONE	3.5	18.0
Density/Modulus	g/KNm	0.0061	0.0095	0.0327	0.0397
CTE/Diffusivity	s/m ² °C	18.8	2.8	3.8	34.8



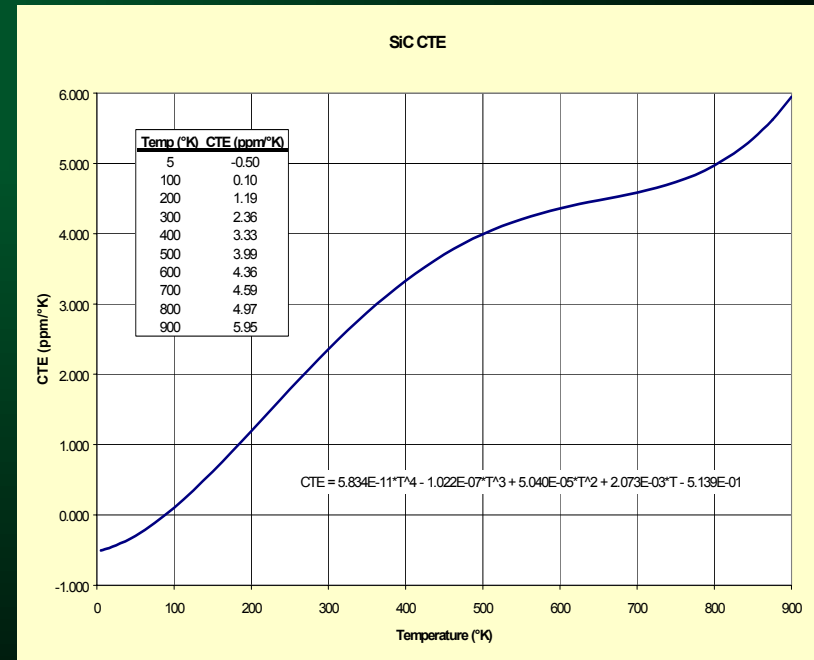
Thermal Response of Xinetics Optical Grade SiC

5°K to 873°K

Thermal Strain Data



Coefficient of thermal Expansion



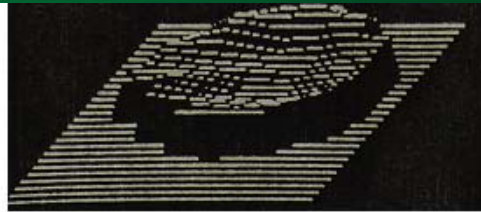


Historical Cryogenic Data on SiC

298 Kelvin to 83 Kelvin



(298 Kelvin; RT)
0.084 W rms



(-272 Kelvin)
0.084 W rms



(201 Kelvin)
0.080 W rms



(133 Kelvin)
0.088 W rms

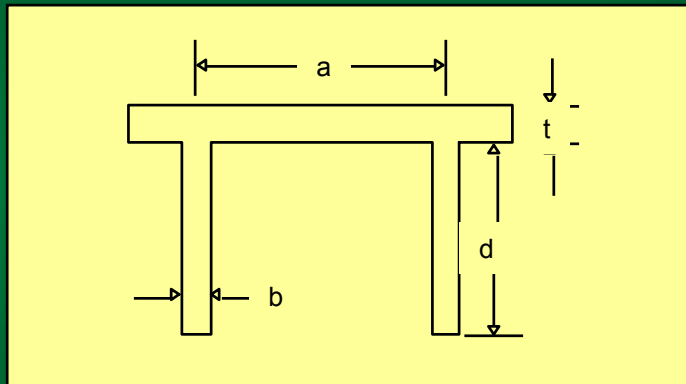


(83 Kelvin)
0.080 W rms

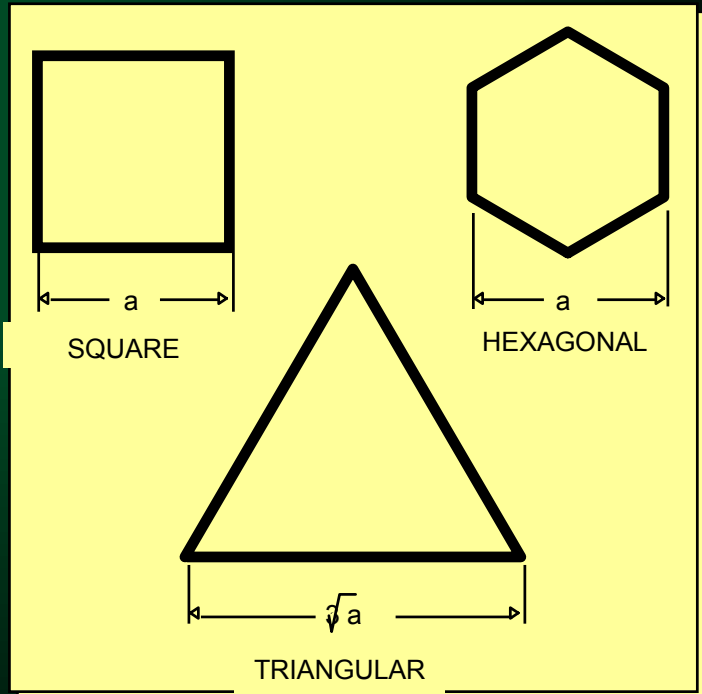


Core Feature Design & Manufacturing Options

CORE CROSS SECTION



MIRROR CORE GEOMETRY OPTIONS





Lightweight Mirror Core Parameters

	Length of Side	Area of Cell	Core Volume per Cell	Face Volume per Cell	Equivalent Weight Thickness
Hexagonal	$\frac{\phi}{\sqrt{3}}$	$\frac{\sqrt{3}\phi^2}{2}$	$\sqrt{3}\phi \ t_c h_c$	$\frac{\sqrt{3}\phi^2}{2} t_f$	$2 \frac{t_c h_c}{\phi} + t_f$
Square	ϕ	ϕ^2	$2\phi \ t_c h_c$	$\phi^2 t_f$	$2 \frac{t_c h_c}{\phi} + t_f$
Triangular	$\sqrt{3}\phi$	$\frac{3\sqrt{3}}{4} \phi^2$	$\frac{3\sqrt{3}}{2} \phi \ t_c h_c$	$\frac{3\sqrt{3}}{4} \phi^2 t_f$	$2 \frac{t_c h_c}{\phi} + t_f$



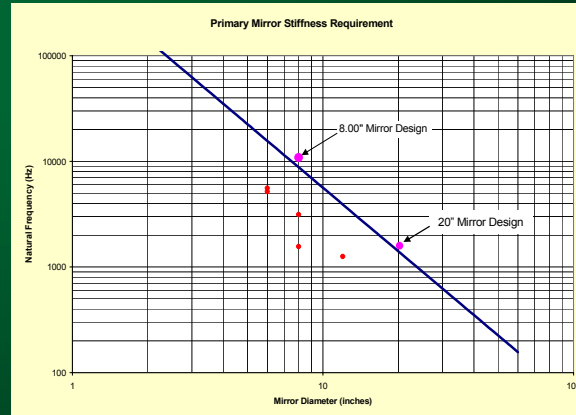
NASA 50-cm Open Back Mirror

... Demonstrates Cathedral Ribs & Low Print Through

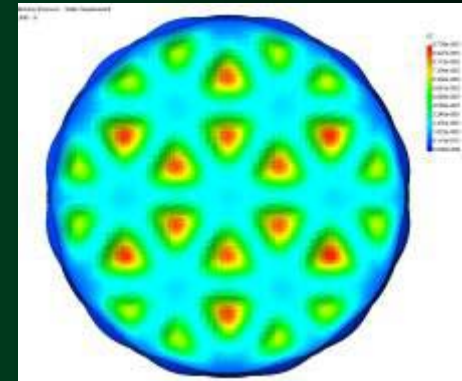
Design Concept



Design Trades



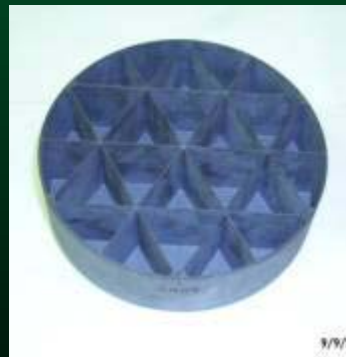
Detailed Analysis



Polishing Experiments



Pathfinder Fabrication



8 inch Diameter

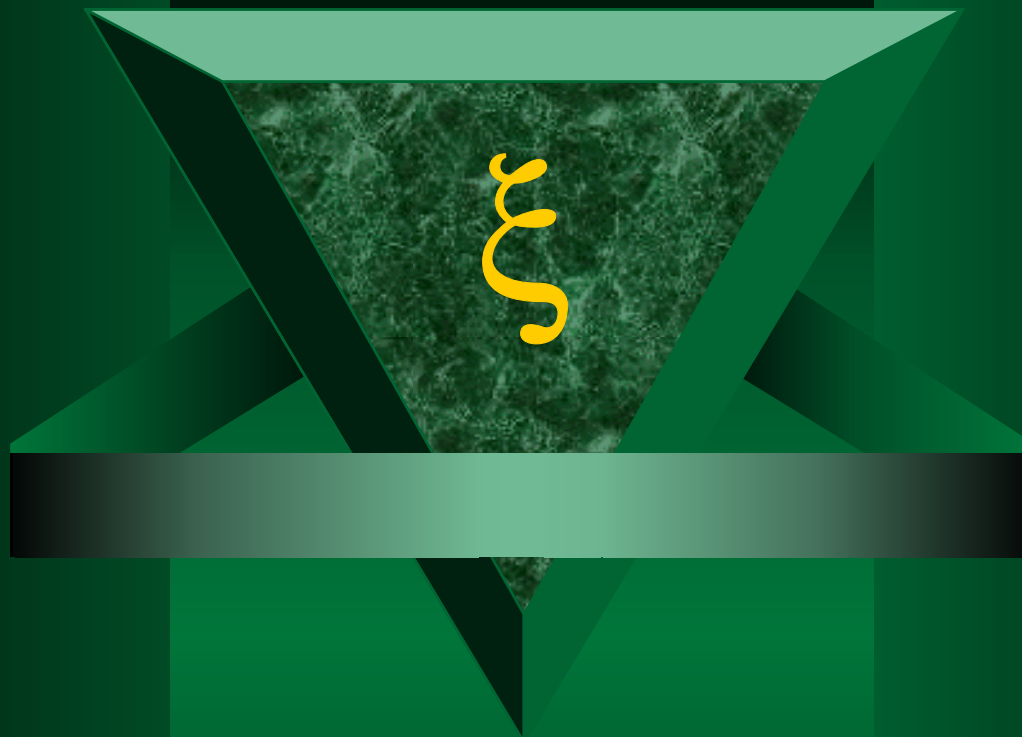
Finished Part



20 inch Diameter, 20 kg/m²

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8 Inch Polishing Pathfinders



Polishing Study

8 Inch Diameter Mirrors

- ◆ Design Approach
 - 8" diameter
 - 2.112 overall thickness
 - 0.093 face thickness
 - 0.067 web thickness
 - 1.334 cell diameter
 - Open back
- ◆ Evaluate polish of lightweight SiC ($\sim 20\text{kg/m}^2$) and transfer lessons learned to 0.5m mirror design.



8 inch SiC Mirror

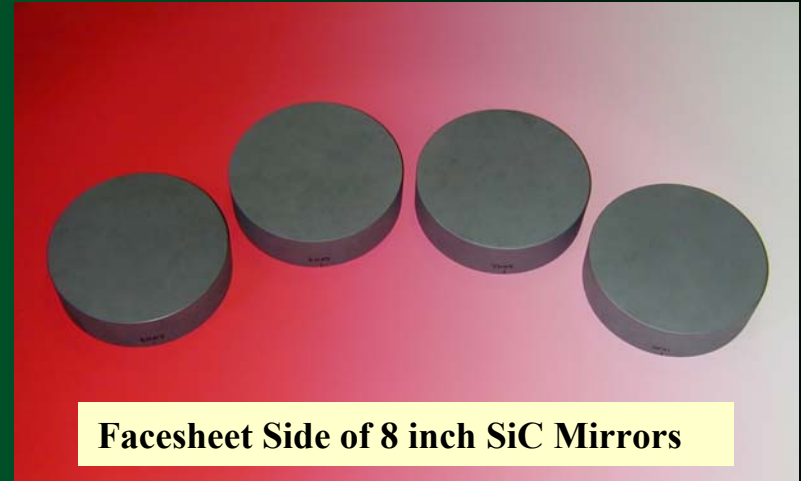


8 inch Mirror Polishing Evaluation

◆ Polishing Study

- Blanks to go to polishing vendors
 - Evaluate results
 - Select vendors
- Evaluate core substructure
- Manipulate / evaluate microstructure

◆ 4 Mirrors Fabricated and Delivered to 3 Polishing Vendors





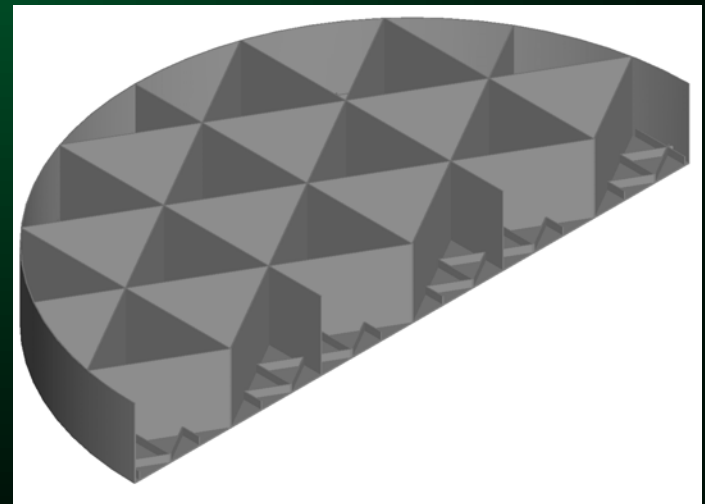
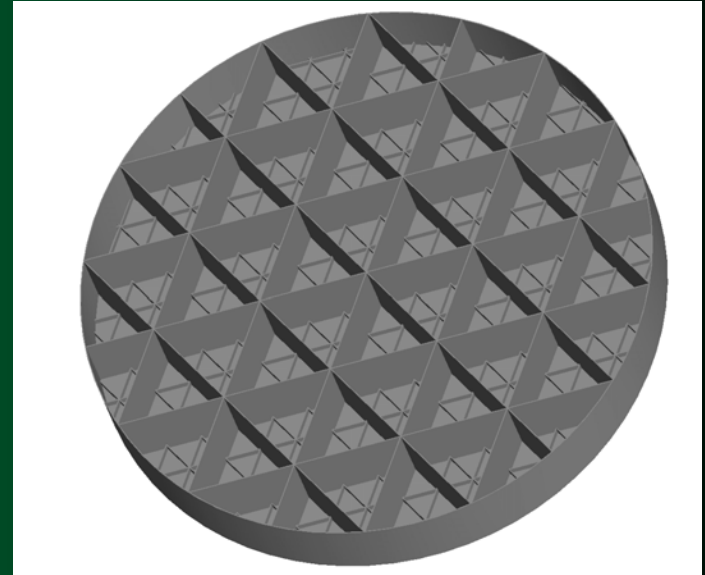
0.5 Meter Mirror



0.5 Meter Mirror Concept

Design Approach

- Primary Ribs .040 inches thick
- Cathedral Ribs used to Increase Stiffness with Minimal Weight Penalty
- Facesheet .060 inches thick with 20 m radius of curvature
- Targeting 10 to 15kg/m² areal density





0.5 Meter Mirror Full Design

Plastic Model

- ◆ Full Scale Model Built by Plastic Writing Method
- ◆ Allows Full Scale Evaluation of Tooling and Fixturing
- ◆ Develop Polishing Process for 0.5 m Mirror

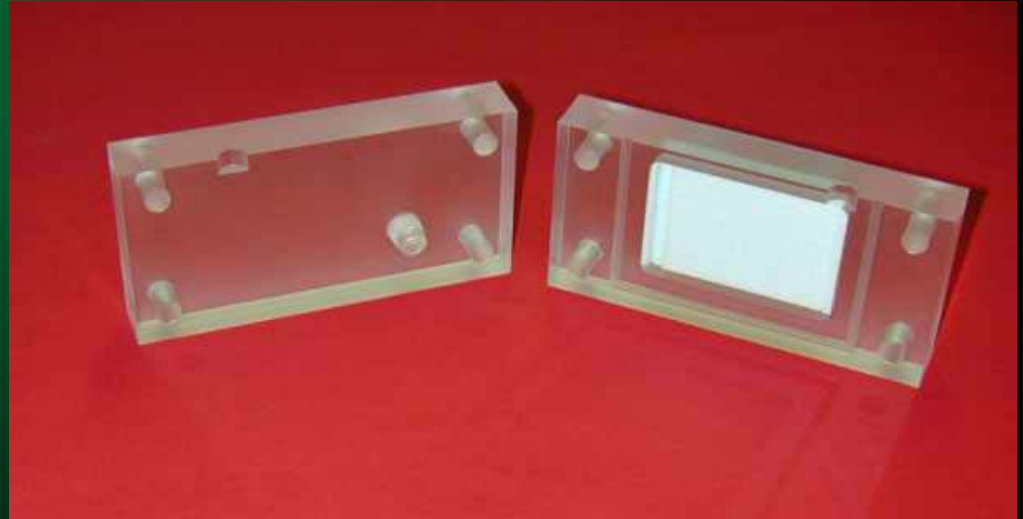




CERAFORM Process Development

... Fluid Flow Models Tailor Areal Density

- Fluid Flow Pathfinders Used to Enable Large Scale Mirrors
- Software Being Used to Model Fluid Flow in Complex Molds
- Slurry Adjustments Made to Enhance Filling



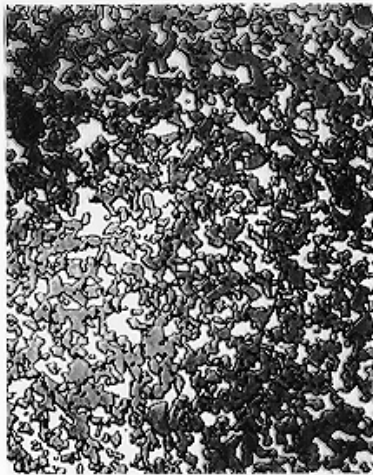


Polishing Bare Silicon Carbide



Microstructure of CERAFORM SiC

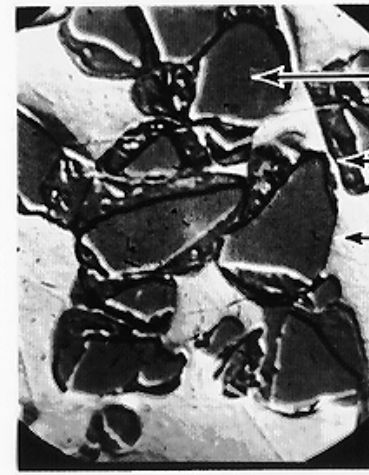
Bimodal Structure key to properties and polish



100μm



50μm



← Silicon Carbide

← Regrowth

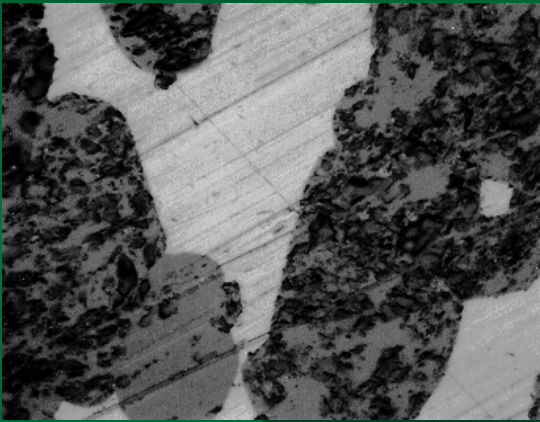
← Silicon

10μm



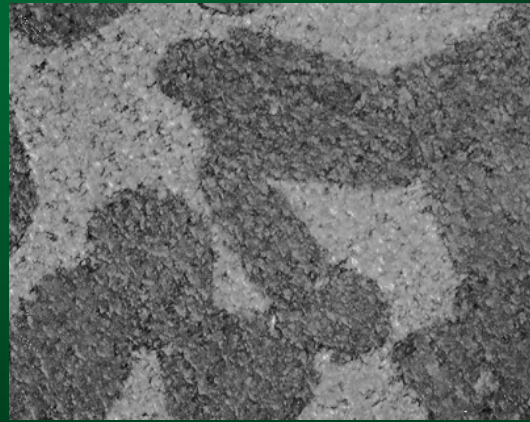
Ceraform SiC Polishing Process

Generating, grinding and polishing bimodal material



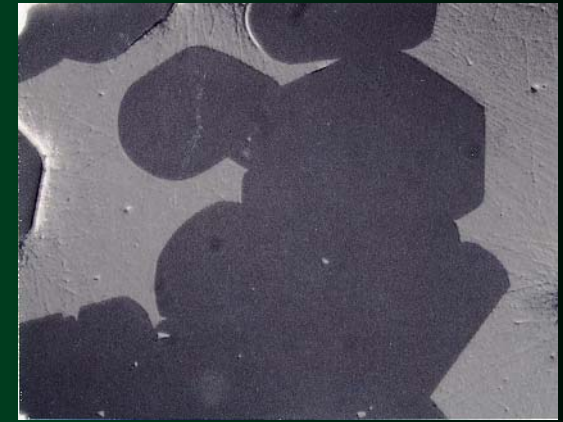
Generated Surface
1000x

- Diamond fixed abrasive
- High removal rates



Precision Grind
1000x

- Loose abrasive hard laps
- Figure mirror surface



Finished Polish
1000x

- Submicron diamond pitch laps
- Control slurry pH

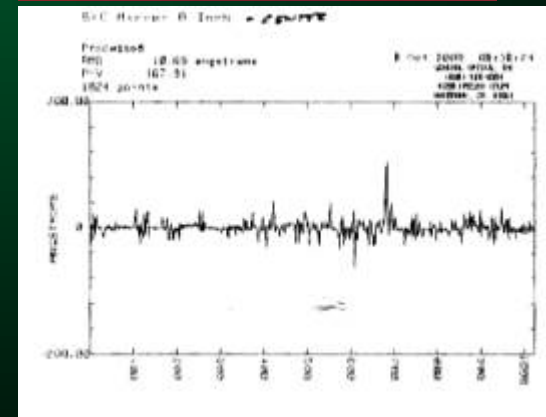
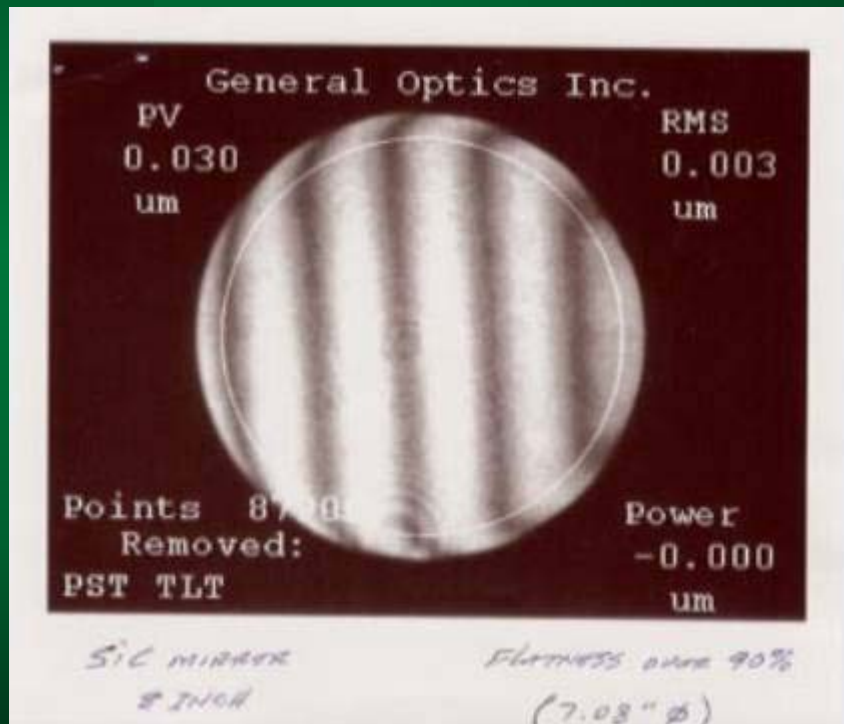
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Wave Precision – 8 –Inch Dia Bare SiC Polish

... Figure = $\lambda/33$ PV, Roughness = 11 Å rms; Cost = \$1500.

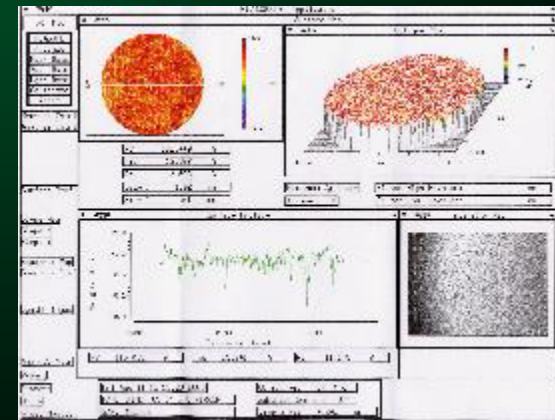
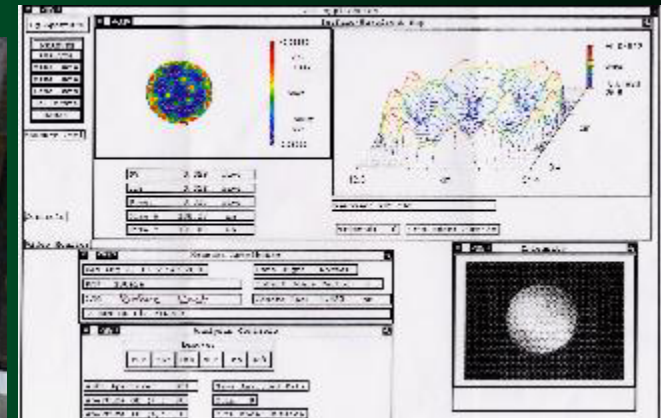
8" Diameter \$1500





Zygo DOP – 8-Inch Dia Bare SiC Polish

... Figure = $\lambda/17$ PV, Roughness = 11 Å rms; Cost = \$7650.



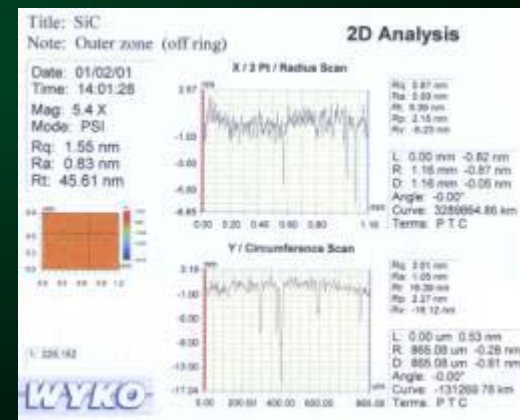
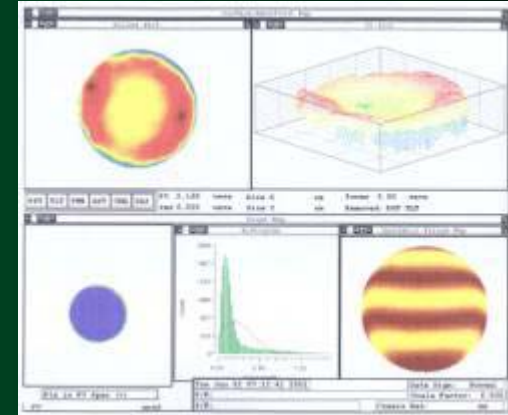
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Eastman Kodak – 8-Inch Dia Bare SiC Polish

... Figure = $\lambda/7$ PV, Roughness = 15.5 Å rms; Cost = \$5625.





Eastman Kodak – 20-Inch Dia Bare SiC Polish

... Figure = 2.6λ PV, Roughness = 14-19 Å rms; Cost = \$45K



*Objective: achieve best surface finish on large part with limited budget and time.

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Silicon Carbide Polishing Developments

... High Material Removal Rates & Smooth Finishes



Rib Structure of 20 inch SiC Mirror

- 15Å rms Finish Routine on Bare SiC
- $\lambda/10$ PV Figure Routine on Bare SiC
- Spherical Removal Rate Established
- Small & Large Shops Evaluated



Mirror	Company	Polishing Method	Figure (PV,waves)	Surface Rough (Å)	Cost
Previous Program	Zygo	Spindle Bare SiC	$\lambda/17$ PV	16 Å rms	\$7650.
8 inch #1	Zygo	Spindle + MRF (Bare)	$\lambda/35$ PV	Before 19 Å rms MRF 181 Å rms	N/A
8 inch #2	Wave Precision	Planetary Bare SiC	$\lambda/33$ PV (90%)	11 Å rms	\$1500.
8 inch #3	Wave Precision	Planetary Si Clad	$\lambda/19$ PV (90%)	2 Å rms	\$2500.
8 inch #4	Kodak	Planetary Bare SiC	$\lambda/7$ PV	16 Å rms	\$5625.
20 inch #1	Kodak	Spherical Bare SiC	TBD	TBD	\$45000.

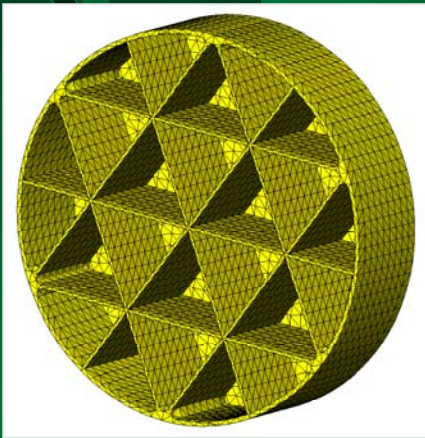
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Large Low Temperature SiC Mirrors

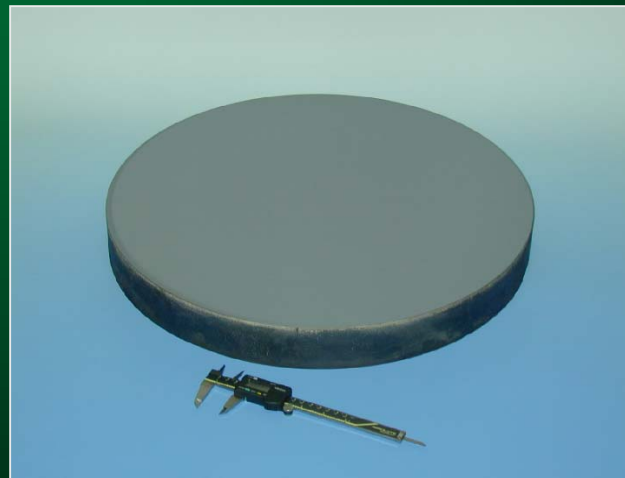
Phase II Delivers 0.5m Silicon Carbide Mirror



Task 1: Design Trades



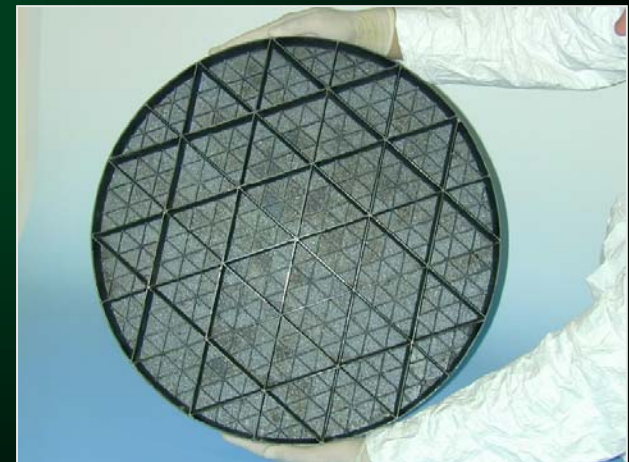
Task 3: Low Areal Density Process



**Task 5: 0.5 meter
Mirror Production and
Polish**



Task 2: 20 cm Polishing Pathfinders



Task 4: Rib Structure Development

Technology
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Silicon Carbide Lightweight Mirrors

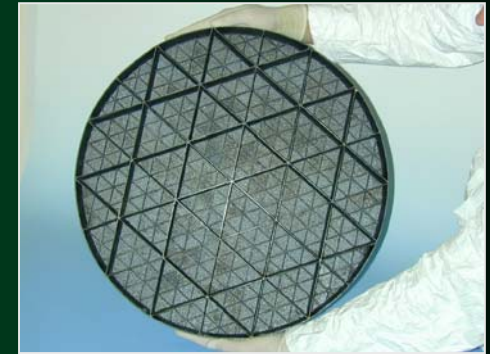
... Open and Closed Back Solutions to 2-Meters



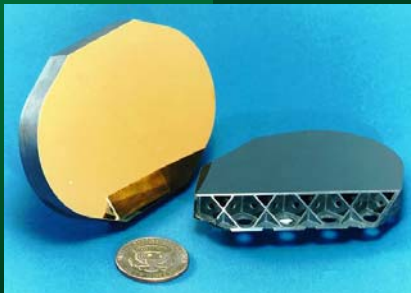
Jerico Open Back Enabler
1.2-m Open Back



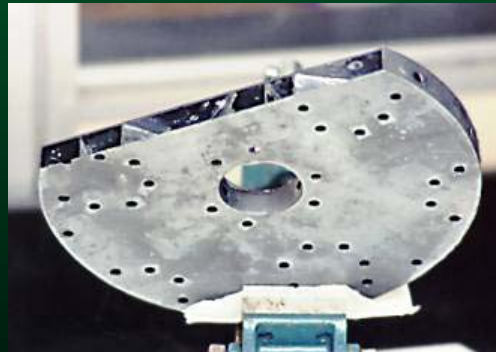
15-cm Cathedral Mirror
Open Back



50-cm NASA Mirror
Open Back



UTOS Closed Back
Enabler



30-cm ASCOT Mirror
Closed Back



1.0-Meter ASCOT Mirror
Closed Back

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